

# GLAST and the Extragalactic Gamma Ray Background

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## Abstract

We show that GLAST should be able to support or rule out the unresolved-blazar hypothesis for the origin of the diffuse, extragalactic gamma ray background.

## 1 Introduction:

Perhaps the most promising model proposed for the origin of the  $\sim$ GeV extragalactic  $\gamma$ -ray background (EGRB), first detected by SAS-2 [Fichtel, Simpson, & Thompson 1978] and later confirmed by EGRET, is that it is the collective emission of an isotropic distribution of faint, unresolved blazars [Stecker & Salamon 1996 and references therein]. EGRET has determined that the EGRB spectrum is consistent with a single power-law,

$$\frac{dN_\gamma}{dE} = (7.32 \pm 0.34) \times 10^{-6} \left( \frac{E}{0.451 \text{ GeV}} \right)^{-2.10 \pm 0.03} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ GeV}^{-1} \quad (1)$$

between 0.1 and  $\sim 50$  GeV (statistics limited) [Sreekumar et al. 1998]. Because GLAST has a roughly energy-independent area of  $10^4 \text{ cm}^2$  above 0.1 GeV (compared to EGRET's  $10^3 \text{ cm}^2$  at 1 GeV and  $10^2 \text{ cm}^2$  at 100 GeV), with an estimated point source sensitivity (PSS) nearly two orders of magnitude lower than EGRET's, GLAST will be able to (a) detect something on the order of  $10^2$  times more blazars than EGRET, and (b) measure the EGRB spectrum to  $> 1$  TeV (assuming the EGRET power law spectrum). These two capabilities will enable GLAST to either strongly support or reject the unresolved-blazar hypothesis for the origin of the EGRB.

## 2 The Unresolved Blazar Model:

To determine the collective output of all  $\gamma$ -ray blazars, one can use the observed EGRET distribution of  $\gamma$ -ray luminosities and extrapolate to obtain a “direct”  $\gamma$ -ray luminosity function (LF)  $f_\gamma(l_\gamma, z)$  [Chiang, et al. 1995] ( $f_\gamma$  units being sources/co-moving volume-differential luminosity), where  $l_\gamma$  is the differential luminosity ( $\text{s}^{-1}$ ) at a (source) fiducial photon energy  $E_f$ , and we assume power law spectra for all sources,  $l(E) = l_\gamma(E/E_f)^{-\alpha}$ . Alternatively, one can make use of much larger catalogs at other wavelengths, and assume some relationship between the source luminosities at the catalog wavelength and the GeV region [Padovani et al. 1993; Stecker, Salamon, & Malkan 1993]. Both methods are fraught with potential errors. In the former method, only the “tip of the iceberg” of the  $\gamma$ -ray LF has been observed by EGRET, and extrapolation to lower luminosities that fall below EGRET's PSS (for any reasonable source distance) involves some level of assumption. In the latter method, the assumption of a linear relation between the luminosities of a source at disparate wavelengths is by no means well established [Padovani, et al. 1993; Muecke, et al 1996, Mattox, et al. 1997].

We used the latter method in the past [Stecker and Salamon 1996] to estimate the contribution of unresolved blazars to the EGRB, and found that up to 100% of EGRET's EGRB can be accounted for. This model assumes a linear relationship between the differential  $\gamma$ -ray luminosity  $l_\gamma$  at  $E_f = 0.1$  GeV and the differential radio luminosity  $l_r$  at 2.7 GHz for all sources, *viz.*,  $l_\gamma = \kappa l_r$ , where  $\kappa$  is a constant. One can then use the measured radio LF  $f_r(l_r, z)$  for blazars (primarily for flat spectrum radio quasars) [Dunlop & Peacock 1990] to calculate the collective  $\gamma$ -ray output of all blazars.

The simplified elements of the calculation follow (the details can be found in Stecker and Salamon 1996). First, the  $\gamma$ -ray and radio LFs are related by  $f_\gamma(l_\gamma, z) = \kappa^{-1} f_r(\kappa^{-1} l_\gamma, z)$ . The number of sources  $\mathcal{N}$  detected by a detector is a function of the detector's point source sensitivity (PSS) at the fiducial energy  $E_f$ ,  $[F(E_f)]_{\min}$ , where the integral  $\gamma$ -ray number flux  $F$  is related to  $l_\gamma$  by

$$F(E) = l_\gamma (E/E_f)^{-\alpha} / 4\pi\alpha(1+\alpha)^{\alpha+1} R_0^2 r^2, \quad (2)$$

where  $R_0 r$  is the luminosity distance to the source. The number of sources at redshift  $z$  seen at Earth with an integral flux  $F(E_f)$  is given by

$$\frac{d\mathcal{N}}{dF(E_f)} \Delta F(E_f) = \int 4\pi R_0^3 r^2 dr f_\gamma(l_\gamma, z(r)) \Delta l_\gamma, \quad (3)$$

where  $l_\gamma$  in the integrand depends on  $z(r)$  and  $F(E_f)$  from Eq.2. Figure 1 shows our 1996 calculations for the number of sources versus flux, compared to the EGRET detections. The cutoff at  $\sim 10^{-7} \text{ cm}^{-2} \text{ s}^{-1}$  for  $E_f = 0.1 \text{ GeV}$ , their quoted PSS, is evident.

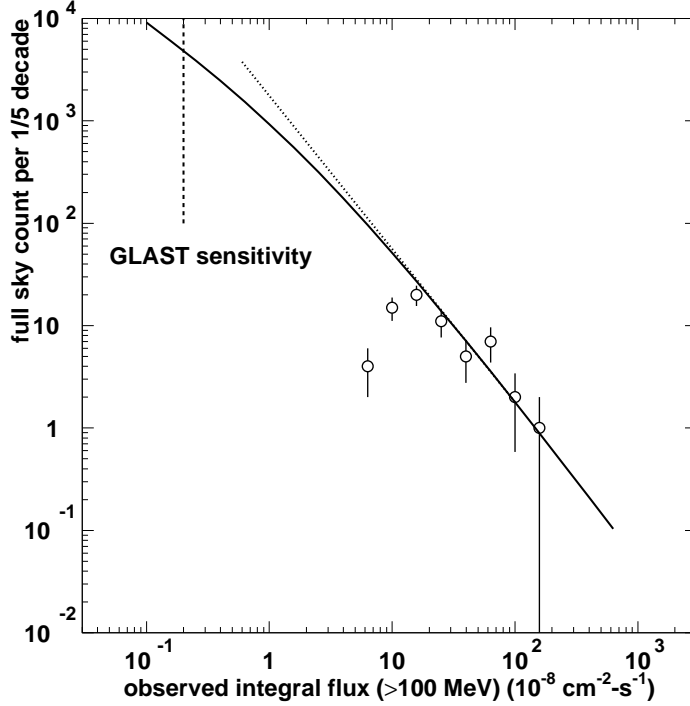


Figure 1: Source number count per one-fifth decade of integral flux at Earth. The straight dotted line is the Euclidean relation  $\mathcal{N}(> F) \propto F^{-3/2}$  for homogeneous distribution of sources. The open circles represent the EGRET blazar detections, and the solid line is the model prediction.

To calculate the EGRB, we integrate over all sources *not* detectable by the telescope to obtain the differential number flux of EGRB photons at an *observed* energy  $E_0$ :

$$\frac{dN_\gamma}{dE}(E_0) = \int 4\pi R_0^3 r^2 dr \int d\alpha p(\alpha) \int_{l_{\min}}^{l_{\max}} \frac{dF}{dE}(E_0(1+z)) f_\gamma(l_\gamma, z) e^{-\tau(E_0, z)} dl_\gamma. \quad (4)$$

This expression includes an integration over the probability distribution of spectral indices  $\alpha$  (based on the 2nd EGRET Catalog [Thompson et al. 1995]). There is also an important attenuation factor in this expression, due to the loss of  $\gamma$ -rays as they propagate through the intergalactic medium and interact with cosmic UV, optical, and IR background photons to produce  $e^\pm$  pairs. Although there are significant uncertainties in estimates of the  $z$ -dependence of the soft photon background [Salamon & Stecker 1998], a qualitative feature cannot be avoided: If a substantial fraction of the EGRB is from high- $z$  flat spectrum radio quasars, a steepening in the spectrum should be seen at energies above 20 GeV. Figure 2 shows the calculated EGRB spectrum (based on EGRET's PSS) compared to EGRET data. The "bump" in the spectrum above 10 GeV is due to there being a finite width in the assumed power-law spectral index distribution of blazars, which produces a summed unabsorbed spectrum with a positive second derivative [Stecker & Salamon 1996]. Although the match between the model's spectrum and the recent EGRET EGRB data [Sreekumar et al. 1998] does not appear to be very good, one must examine it in the light of the assumptions and uncertainties. The location and amplitude of the "bump" depend upon the amount of high redshift absorption, which, in turn, depend upon uncertain UV and optical soft photon background densities [Salamon & Stecker 1998]. The "bump" also depends upon the poorly known blazar spectral index distribution, which we have assumed to be independent of quiescent-state luminosity. Finally, we note that the assumed power-law form for high redshift quasars above 10 GeV energy is highly questionable in light of the predictions of the Compton models for  $\gamma$ -ray emission from these sources; in fact their spectra are predicted to steepen at these energies. We also note that EGRET's EGRB error bars are systematic, not statistical and that Sreekumar et al. [1998] have stated that the model cannot be ruled out based on the EGRET data.

### 3 GLAST and the EGRB:

Figure 1 shows that  $\mathcal{O}(10^3)$  blazars should be detectable by GLAST, assuming it achieves a PSS of  $\sim 2 \times 10^{-9} \text{ cm}^{-2}\text{s}^{-1}$ , and Figure 2 shows that this should reduce the EGRB by a factor of  $\sim 2$  for  $E > 1 \text{ GeV}$ . These predictions are arrived at by replacing EGRET's PSS with GLAST's in our 1996 model.

Figure 2 shows our predicted reduction in the EGRB from unresolved blazars to be observed by GLAST compared with that observed by EGRET. The dashed line in Figure 2 represents the energy interval in which it is difficult to determine GLAST's EGRB spectrum, due to the effect of worsening angular resolution with decreasing energy. For a lower PSS level, the number of detectable sources is larger. However, the angular resolution limits the number of distinct sources one can identify, crudely given by  $\mathcal{N}(E) \approx 4\pi/\pi\sigma_\theta^2(E)$ , where  $\sigma_\theta(E)$  is the energy-dependent angular resolution. When  $\mathcal{N}( > F_{min} ) > \mathcal{N}(E)$ , individual sources are no longer separable from the EGRB. With GLAST's proposed angular resolution function (GLAST Science Document), the equality  $\mathcal{N}( > F_{min} ) = \mathcal{N}(E)$  occurs at  $E$  somewhat less than 1 GeV; thus for  $E < 1 \text{ GeV}$  there is not as much a reduction in the level of the EGRB (compared to EGRET) as for energies  $E > 1 \text{ GeV}$ .

We conclude that GLAST can test the unresolved blazar background model in three ways: (1) GLAST should see roughly 2 orders of magnitude more blazars than EGRET because of its ability to detect the fainter blazars which contribute to the EGRB in our model. Moreover, GLAST can test our assumption of an average linear relation between  $\gamma$ -ray and radio flux and our assumed redshift distribution of blazars by testing the details of our source count versus flux prediction. (2) With GLAST's improved PSS leading to more blazars being resolved out, fewer unresolved blazars will be left to contribute to the EGRB, thus reducing the level of the measured EGRB compared to EGRET's. (3) GLAST's much greater aperture at 100 GeV will allow a determination of whether or not a steepening exists in the EGRB, since the number of EGRB  $\gamma$ -rays recorded by GLAST above 100 GeV will be of order  $10^3$  to  $10^4$ , assuming a continuation of the EGRET power law spectrum.

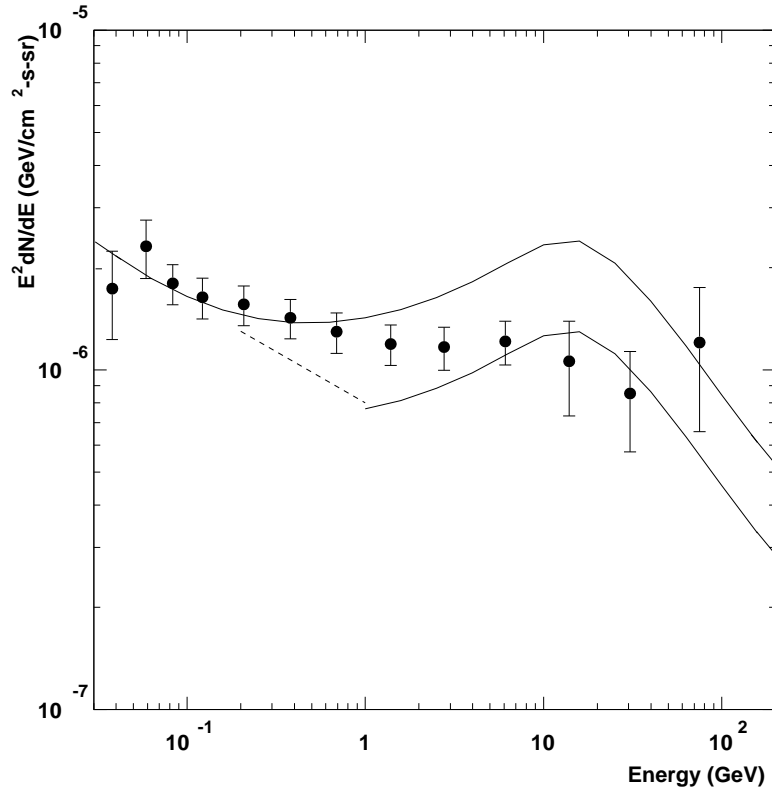


Figure 2: The upper and lower solid curves correspond to model predictions for the EGRB spectrum given EGRET's and GLAST's PSS (respectively). The data points are from the latest EGRET EGRB analysis [Sreekumar et al. 1998]. The dashed line segment in the lower curve corresponds to the energy interval where increasing source confusion, owing to worsening angular resolution at lower energies, prevents the discernment of point sources, which then contribute to the EGRB.

However, this last test must be qualified because of the unknown amount of steepening in the high redshift quasar spectra above 10 GeV which can mimic an absorption effect.

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